3:2 PULL-DOWN FILM MODE DETECTION USING FUZZY LOGIC

This application is a continuation of U.S. Patent Application No. 09/822,707, filed March 30, 2001, and is herein incorporated by reference.

BACKGROUND OF THE INVENTION

Before being displayed by a progressive display device, NTSC video fields need to be deinterlaced first. As displayed on the progressive display device, the image quality of the deinterlaced fields depends on the type of deinterlacing process performed on the fields.

On the one hand, if the fields have originated from film frames by 3:2 pull-down, then deinterlacing the fields simply means merging fields that have originated from the same frame. As such, deinterlacing 3:2 pull-downed fields produces the best image quality on a progressive display device. However, on the other hand, if the fields are not generated by 3:2 pull-down but are deinterlaced as such, then the image quality of the progressively displayed images an be degraded by undesirable image saw-tooth.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings which are incorporated in and form a part of this specification, illustrate embodiments of the invention and together with the description, serve to explain the principles of the invention:

Figure 1 is a flow chart comprising steps performed for 3:2 pull-down film mode detection in accordance with one embodiment of the invention.

Figure 2 shows a system diagram for 3:2 pull-down film mode detection in accordance with one embodiment of the invention.

Figure 3 shows a block diagram for generating the accumulated difference between two fields in accordance with one embodiment of the invention.

Figure 4 shows a block diagram for generating a reference sequence of symbols that is used for detecting 3:2 pull-down film mode in accordance with one embodiment of the invention.

Figure 5 shows a decision rule used to indicate the detection of the 3:2 pull-down film mode in accordance with one embodiment of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Reference is made in detail to the preferred embodiments of the invention. While the invention is described in conjunction with the preferred embodiments, the invention is not intended to be limited by these preferred embodiments. On the contrary, the invention is intended to cover alternatives, modification and equivalents, which may be included within the spirit and scope of the invention as defined by the appended claims. Furthermore, in the following detailed description of the invention, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, as is obvious to one ordinarily skilled in the art, the invention may be practiced without these specific details. In other instances, well-known methods, procedures, components, and circuits have not been described in detail so that aspects of the invention will not be obscured.

Referring now to Figure 1, a flow chart 100 is shown outlining steps performed for 3:2 pull-down film mode detection in accordance with one embodiment of the invention.

In step 105, a sequence of accumulated sums
$\{ S[i] \} = \{ \ldots, S[n-1], S[n], S[n+1], \ldots \}$ is generated from a sequence of NTSC video fields $\{ F[i] \} = \{ \ldots, F[n-1], F[n], F[n+1], \ldots \}$.

Specifically, in step 105, a NTSC video field $F[n]$ and $F[n-2]$ is two fields ahead of $F[n]$ are compared over a common designated set of pixel positions. More specifically, for each designated pixel position (i, j), the absolute value of the difference between the luma values $Y[n]$ of $F[n]$ and $Y[n-2]$ of $F[n-2]$ is generated. The difference between the luma values $Y[n]$ and $Y[n-2]$ at the pixel (i, j) is denoted $a(i, j)$, with its absolute value denoted $| a(i, j) |$. Then, a sum $S[n]$ of the absolute values over all the designated pixel positions is generated, wherein $S[n] = \sum | a(i, j) |$, where (i, j) varies over all pixel positions in the common designated set above.

In step 110, $Z[n-1]$, $Z[n-2]$, $Z[n-3]$ and $Z[n-4]$ are generated, wherein
$Z[n-1] = S[n] - S[n-1]$,
$Z[n-2] = S[n] - S[n-2]$,
$Z[n-3] = S[n] - S[n-3]$, and
$Z[n-4] = S[n] - S[n-4]$.

In step 115, $X[n-1]$, $X[n-2]$, $X[n-3]$ and $X[n-4]$ are generated, wherein
$X[n-1] = | Z[n-1] |$,
$X[n-2] = | Z[n-2] |$,

X[n-3] = | Z[n-3] |, and

X[n-4] = | Z[n-4] |.

In step 120, X[n-1], X[n-2], X[n-3] and X[n-4] are fuzzified with two fuzzy sets of "BIG" and "SMALL" by defining fuzzy membership functions of Big(X[.]) and Small(X[.]).

Specifically, Big(X[.]) assigns to every X[.] value its fuzzy membership in the fuzzy set BIG. In doing so, four numerical values of Big(X[n-1]), Big(X[n-2]), Big(X[n-3]), and Big(X[n-4]) are obtained. Also, Small(X[.]) assigns to every X[.] value its fuzzy membership in the fuzzy set SMALL. In doing so, four numerical values of Small(X[n-1]), Small(X[n-2]), Small (X[n-3]), and Small(X[n-4]) are obtained.

In step 125, a reference sequence of symbols { P[i] }={..., P[n-1], P[n], P[n+1], ...} is generated in one-to-one correspondence with the sequence of accumulated sums

{ S[i] }={ ...., S[n-1], S[n], S[n+1], ...}. Each P value P[i] can take on either an 'H' (High) or a 'L' (Low). Moreover, whether a P value such as P[i] takes on 'H' or 'L' is determined by applying a set of fuzzy inference rules. If a P value (e.g., P[n]) is assigned the symbol 'L' by these fuzzy inference rules, then X[n-1], X[n-2], X[n-3] and X[n-4] are classified as belonging to the fuzzy set of BIG. Otherwise, if a P value (e.g., P[n]) is assigned the symbol 'H' by these fuzzy inference rules, then at least one of X[n-1], X[n-2], X[n-3] and X[n-4] is classified as belonging to the fuzzy set of SMALL.

Specifically, these fuzzy inference rules can be summarized succinctly as follows:

If X[n-1] is BIG and X[n-2] is BIG and X[n-3] is BIG and X[n-4] is BIG, then P[n] is assigned 'L' to indicate that all of X[n-1], X[n-2], X[n-3], and X[n-4] are BIG. Otherwise, P[n] is assigned 'H' to indicate that at least one of X[n-1], X[n-2], X[n-3] and X[n-4] is SMALL.

These fuzzy inference rules are implemented by performing fuzzy inference algorithm. The fuzzy inference algorithm takes four X[.] values such as X[n-1], X[n-2], X[n-3] and X[n-4] as numerical inputs, and generates therefrom a numerical output g. Specifically, the fuzzy inference algorithm takes X[n-1], X[n-2], X[n-3] and X[n-4] and generates therefrom a collection of fuzzy subsets C[1], C[2], ... and C[n], wherein each fuzzy subset is associated with one of the fuzzy inference rules. Then

the fuzzy inference algorithm forms a fuzzy union set D of the fuzzy subsets C[1], C[2], ... and C[n]. In turn, the fuzzy inference algorithm defuzzifies the fuzzy union set D to obtain the numerical output g. The numerical range of g is partitioned into two intervals, a Low interval and a High interval. If g falls within the Low interval, the P[n] is assigned the symbol of 'L'. Otherwise if g falls within the High interval, then P[n] is assigned the symbol of 'H'.

As mentioned above, if a P value (e.g., P[n]) is assigned the symbol "L' by these fuzzy inference rules (implemented through fuzzy inference algorithm), then this P value's corresponding S value (i.e., S[n]) is separated from the previous four S values (i.e., S{n-1], S[n-2], S[n-3] and S[n-4] by big gaps (i.e., gap X[n-1] is BIG, gax X[n-2] is BIG, gap X[n-3] is BIG, and gap X[n-4] is BIG). Otherwise, if a P value (e.g., P[n] is assigned the symbol 'H' by these fuzzy inference rules (implemented through fuzzy inference algorithm), then one or more of the gaps (i.e., gap X[n-1], gap X[n-2], gap X[n-3], and gap X[n-4]) is SMALL.

As understood herein the defuzzification is performed using the center-of-gravity defuzzification technique. However, in another embodiment other type of defuzzification technique can be used.

In query step 130, a check is made to determine if the generated reference sequence {P[i]} exhibits a repeating pattern that characterized 3:2 pull-downed fields.

Specifically, the repeating pattern that characterized 3:2 pull-downed fields can be 'HHHHL', 'HHHLH', 'HHLHH', 'HLHHH', or 'LHHHH'. If none of these patterns is found to be repeating in the reference sequence, then the fields are not designated as 3:2 pull-downed fields. As such, step 135 is performed wherein these fields are designated as fields not generated from film source via 3:2 pull-down. If one of these patterns is found to be repeating at least m times (where m is a positive integer), then the fields are treated as possible candidates as 3:2 pull-downed fields. As such, an extra query step 140 is performed.

In query step 140, the signs of Z[n-1], Z[n-2], Z[n-3] and Z[n-4] are also used to rule out possible erroneous symbol assignment in the reference sequence {P[i]}. If there is symbol mis-assignment, then step 135 is performed. If there is no symbol mis-assignment, then step 145 is performed.

In step 135, these fields are designated as fields not generated from film source via 3:2 pull-down process.

In step 145, these fields are designated as fields generated from film source via 3:2 pull-down process.

Referring now to Figure 2, a system 200 is shown for 3:2 pull-down film mode detection in accordance with one embodiment of the invention. System 200 is adapted to detect the NTSC video fields that have been generated by 3:2 pull-down from film frames. Moreover, unless their 3:2 pull-downed origin can be ascertained, these fields are not designated by system 200 as 3:2 pull-downed fields.

System 200 comprises a two-field delay 210, a difference accumulated 220 and a film/video mode decision unit 230.

Specifically, two-field delay 210 receives a first video field stream that is a NTSC video field stream, then generates therefrom a second field stream that is a two-field delay version of the first video field stream. Difference accumulate 220 receives both the first and the second field streams, then generates therefrom a stream of accumulated field differences between the first and the second field streams. Decision unit 230 receives this difference stream and then determines if the NTSC video fields have been generated by 3:2 pull-down from film frames. As will be explained, decision unit 230 incorporates fuzzy logic to make this determination.

Referring now to Figure 3, difference accumulate unit 220 (previously from Figure 2) is shown in more details in accordance with one embodiment of the invention. As described above, unit 220 is adapted for generating the accumulated difference between two fields that are one field apart (e.g., F[n] and F[n-2]).

Unit 220 comprises a subtraction unit 310, an absolute value unit 320 and a summing unit 330.

Subtraction unit 310 receives both a field F[n] from the first stream and a field F[n-2] from the two-field delay stream, wherein F[n-2] is positioned 2 fields ahead of F[n] within the incoming field stream. Specifically, a "common detection area" (a set of pixel positions at which the luma values Y[n] and Y[n-2] are subtracted from each other) is first designated for the two incoming fields. Specifically, at each pixel position (i, j) of the common detection area, the luma value Y[n] of the field F[n] at pixel (i, j) is subtracted from the luma value Y[n-2] at pixel (i, j) of the field F[n-2]. As a result, the luma difference a(i, j) at pixel (i, j) is generated.

Absolute value unit 320 receives the a(i,j)'s and generates therefrom their absolute values: | a(i, j) |'s.

Summing unit 330 receives | a(i, j) |'s and generates therefrom their sum S[n] = $\sum$| a(i, j) |, where the sum is taken over all (i, j)'s within the designated common pixel positions of both fields.

Continuing with Figure 3, unit 220 over time generates as its output a stream of S values: {... S[n-1], S[n], S[n+1], ...}. Specifically, unit 220 receives the next pair of fields F[n+1] and F[n-1] and generates therefrom S[n+1]. Similarly, unit 220 receives the next pair of fields F[n+2] and F[n-1] and generates therefrom S[n+1]. Similarly, unit 220, receives the next pair of fields F[n+2] and F[n] an generates therefrom S[n+2], and so on.

Referring now to Figure 4, decision unit 230 (previously from Figure 2) is shown in more details in accordance with one embodiment of the invention. Decision unit 230 uses fuzzy logic for generating a reference sequence of symbols {P[i]}, wherein each symbol can either be an 'H' (High) or a 'L' (Low). This reference sequence is adapted as a determining factor for detecting 3:2 pull-down film origin of the NTSC video fields.

Decision unit 230 comprises a relative value unit 410, a fuzzy logic decision unit 430 and a decision unit 440. Relative value unit 410 further comprises four subtraction units 411-414 and four absolute value units 421-424. Relative value unit 410 provides data for fuzzy logic decision unit 420 to generate the reference sequence to be provided to film/video mode evaluation unit 430.

Specifically, relative value unit 410 can receive five S values as inputs. For example, as shown, these S values can be S[n], S[n-1], S[n-2], S[n-3] and S[n-4]. In turn, relative value unit 410 generates therefrom four outputs X[n-1], X[n-2], X[n-3] and X[n-4] that indicate respectively the relative differences between S[n] and the other four S values. More specifically, as shown, X[n-1] is the absolute value of the difference Z[n-1] between S[n] and S[n-1]; X[n-2] is the absolute value of the difference Z[n-2] between S[n] and S[n-2]; X[n-3] is the absolute value of the difference Z[n-3] between S[n] and S[n-3] and X[n-4] is the absolute value of the difference Z[n-4] between S[n] and S[n-4]. The differences Z[n-1], Z[n-2], Z[n-3] and Z[n-4] are provided to unit 440.

Continuing with Figure 4, fuzzy decision unit 430 receives X[n-1], X[n-2], X[n-3] and X[n-4] and applies fuzzy logic to generate therefrom a symbol P[n] belonging to the reference sequence {P[i]}. P[n] can take on either the symbol of 'H' or the symbol of 'L'. Whether P[n] is assigned 'H' or 'L' is determined by fuzzy

logic as explained in the discussion with respect to step 125 of Figure 1. Each symbol in the reference sequence is assigned to an S value in order to characterize the sizes of the four gaps (i.e., X[n-1], X[n-2], X[n-3] and X[n-4] between the S value (i.e., S[n]) and its previous four S values {i.e., S[n-1], S[n-2], S[n-3] and S[n-4]). For example, the nth symbol (P[n]) is assigned to the nth S value (S[n]). Similarly, the (n+1)th symbol (P[n+1] is assigned to the (n+1)th S value (S[n+1]), and so on. Moreover, if P[n] is 'L', then the gap sizes (i.e., X[n-1], X[n-2], Xn-3] and X[n-4] are characterized as BIG by the fuzzy inference rules implemented in the present embodiment. Otherwise, if P[n] is 'H', then one or more of the gap sizes, (i.e., X[n-1], X[n-2], X[n-3] and X[n-4]) are characterized as SMALL by the fuzzy inference rules implemented in the present embodiment.

Referring still to Figure 4, evaluation unit 440 receives the reference sequence {P[i]}, Z[n-1], Z[n-2], Z[n-3] and Z[n-4], then determines therefrom whether or not to the fields are 3:2 pull-downed from film source. How decision unit 440 arrives at its determination is described in Figure 5.

Referring now to Figure 5 in view of Figure 4, a decision rule 500 adapted to ascertain 3:2 pull-down origin of video fields is depicted in accordance with one embodiment of the invention. Specifically, decision rule 400 is depicted together with a cyclic pattern 510 that characterized a sequence of 3:2 pull-downed fields.

The reference sequence {P[i]} is generated by fuzzy decision unit (see 430 of Figure 4) for detecting 3:2 pull-downed fields. Specifically, if the fields have been generated by 3:2 pull-down from film frames, then the reference sequence generated by fuzzy decision unit 430 exhibits a repeating pattern 510 that characterizes 3:2 pull-downed fields. Specifically, within the reference sequence, a cyclic symbol pattern formed by repeating the pattern of 'HHHHL' can indicate 3:2 pull-downed fields.

However, as understood herein a cyclic symbol pattern can start from any place of cyclic pattern 510. For example, in addition to 'HHHHL' above, each of the following four patterns might also be found repeated (in the reference sequence): 'HHHLH', 'HHLHH', 'HLHHH', and 'LHHHH'.

Furthermore, within evaluation unit 440, the signs of Z[n-1], Z[n-2], Z[n-3] and Z[n-4] are also used to rule out possible erroneous symbol assignment in {P[i]}. In so doing, evaluation unit 440 can avoid erroneously designating fields as 3:2 pull-downed fields from film source.

The foregoing descriptions of specific embodiments of the invention have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed. Obviously, many modifications and variations are possible in light of the above teaching. The

5   embodiments were chosen and described in order to explain the principles and the application of the invention, thereby enabling others skilled in the art to utilize the invention in its various embodiments and modifications according to the particular purpose contemplated. The scope of the invention is intended to be define by the claims appended hereto and their equivalents.